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DoD Corrosion Prevention and Control Program

Implementation of Polyurea Applications for Wastewater System Corrosion-Mitigation Projects

Final Report on Project F15-AR04

Clint A. Wilson, Jaclyn S. Mathis, Wesley J. Kramer, and
Rachel E. Kizer

July 2017

Construction Engineering
Research Laboratory

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Implementation of Polyurea Applications for Wastewater System Corrosion-Mitigation Projects

Final Report on Project F15-AR04

Clint A. Wilson, Jaclyn S. Mathis, Wesley J. Kramer, and Rachel E. Kizer

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Final report

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Prepared for Office of the Secretary of Defense
Washington, DC 20301-3090

Under Project F15-AR04, "Polyurea Coating for Rehabilitation of Concrete and Metal Infrastructure"

Abstract

Corrosion of reinforced concrete in wastewater systems due to microbially generated sulfuric acid is a major problem for Department of Defense (DoD) facilities. A previous DoD-sponsored demonstration and validation project showed that liquid-applied polyurea liner technology can effectively rehabilitate wastewater systems and prevent further corrosion, but more work was needed before recommending the technology's adoption DoD-wide. This follow-on study explores and discusses additional issues and makes recommendations about polyurea's use. Issues explored include behavior under high-velocity flow conditions, additional application configurations, field repair methods, behavior on steel substrates, comparisons with other rehabilitation products, industry perception and use, and sewer inflow and infiltration. The approach included a survey of municipal practices plus a literature review. Results showed that polyurea liners can be useful in mitigating the effects of corrosion, especially when sewer and wastewater environments are subject to movement, abrasion, or ultraviolet radiation. Recommendations to the DoD's Corrosion Prevention and Control Program include adding a polyurea section to UFGS 09 96 00 High Performance Coatings and referencing UFGS 09 96 00 within UFC 3-240-01 Wastewater Collection. The return on investment for this effort is 35.24.

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Preface

This work was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control Project FY15-AR04, “Polyurea Coating for Rehabilitation of Concrete and Metal Infrastructure.” The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Mr. Daniel J. Dunmire (OUSD (AT&L)), Mr. Ramon Sison (IMPW), and Mr. Paul Richardson (DAIM-ODF).

The work was performed by the Engineering and Materials Branch (CEERD-CFM), Facilities Division (CF) of the U.S. Army Engineer Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. At the time of publication, Ms. Vicki L. Van Blaricum was Chief, CEERD-CFM; Mr. Donald K. Hicks was Chief, CEERD-CF; and Mr. Kurt Kinnevan, CEERD-CZT, was Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

The Commander of ERDC was COL Bryan S. Green, and the Director was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
microinches	0.0254	micrometers
microns	1.0 E-06	meters
miles (U.S. statute)	1,609.347	meters
mils	0.0254	millimeters
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

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1 Introduction

1.1 Problem statement

Corrosion of sewer systems causes great expense to the Department of Defense (DoD). According to Herzberg, O'Meara, and Stroh (2014), the corrosion of reinforced concrete in wastewater systems is one of the DoD's 25 most costly problems. Experts estimate that in the United States alone, over $1 trillion will be spent over the next 25 years to mitigate this type of corrosion (Primeaux II and Gomez 2014, 28). A sewer system failure can also lead to service interruptions and safety risks. Sewer systems are mostly constructed of reinforced concrete or masonry, and these materials are under constant corrosive attack by typical environmental factors as well as microbially generated sulfuric acid. Any effective alternative to full system replacement, such as in situ rehabilitation, must both prevent further corrosive damage and mitigate damage that has already occurred.

A demonstration/validation project completed under the DoD Corrosion Prevention and Control (CPC) Program and performed by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), showed that liquid-applied polyurea liner technology can effectively rehabilitate wastewater systems that have already experienced corrosion damage (Wilson, Drozdz, and Mathis 2016). In that study, a proprietary three-layer application of polyurea was shown to mitigate the effects of biogenic sulfide corrosion, when applied to concrete and masonry materials. The authors recommended that before formally recommending incorporation of the technology into DoD specifications and criteria, further study of polyurea would be needed to address questions such as the specific environmental conditions in which polyurea would provide an effective and cost-efficient solution to wastewater system corrosion.

This report addresses those research questions raised in Wilson, Drozdz, and Mathis (2016).

1.2 Objective

The objective of this project is to address technical issues that will affect DoD-wide implementation of liquid-applied polyurea liner materials as an option for corrosion prevention and control in reinforced concrete and metal wastewater infrastructure.

1.3 Approach

ERDC-CERL performed an investigation to identify the applicability and limitations of liquid polyurea materials to prevent and/or mitigate corrosion in wastewater systems. Stormwater applications were also considered for systems subject to abrasive erosion or cavitation conditions. Such applications were found to be less common in practice, however, so the principal focus of the study was wastewater system applications.

The tangible product of this work includes recommendations for revising appropriate sections of Unified Facilities Guide Specifications (UFGS) and Unified Facilities Criteria (UFC) to permit the use of polyurea liner systems as an option for wastewater system corrosion mitigation (see appendix). This approach for technology implementation includes recommending changes to the criteria change request (CCR) process (see appendix).

The research methods were:

- a review of scientific and technical literature on relevant polyurea applications,
- a user survey targeting municipalities with experience using polyurea liner materials in wastewater systems, and
- a market survey of polyurea manufacturers.

Completion of the research objective did not require a field demonstration, so the study was not subject to the metrics typically applied to a CPC project.

2 Technology Investigation

2.1 Technology overview

Liquid-applied polyurea materials have been used by several U.S. municipalities in various applications. To supplement and extend the polyurea demonstration results reported by Wilson, Drozdz, and Mathis (2016), the authors studied the technical and industrial literature on non-DoD applications to establish a broader understanding of the strengths and weaknesses of this material.

As used in wastewater and stormwater systems, polyurea is typically spray-applied as a high-build coating (thicker than 5 mils). The material creates a tough, waterproof barrier that protects the substrate from corrosion caused by impact damage, abrasion, ultraviolet (UV) radiation damage, sulfuric acid, and other harsh chemicals (Primeaux II and Gomez 2014). The cured polyurea forms a type of elastomer produced by a dual-component reaction of isocyanate and an amine (Naval Research Laboratory 2015). Due to the fast cure time of the applied liner, the two reactants are typically stored separately and combined only during the application process.

Hydrogen bonds in polyurea make it more flexible than materials like epoxy or polyurethane. When stress is applied to the cured material, the hydrogen bonds break while the covalent, polymer bonds remain intact. When the stress is removed, the hydrogen bonds reform to prevent any permanent damage (Naval Research Laboratory 2015). These properties qualify some formulations of polyurea as Class III semi-structural liners, meaning that the material can span gaps and resist buckling from an external hydrostatic load or vacuum (Morrison et al. 2013, 74). However, it is not strong enough to correct structural deficiencies in concrete or masonry. In addition to these properties, the chemical makeup of this substance also gives it the unique ability to be applied in a wide range of temperatures (Wilson, Drozdz, and Mathis 2016, 39).

Polyurea isolates the substrate from the corrosive interior environment. Various multilayer specifications are available for different substrates. As with most coatings, some method of surface preparation of the substrate is specified to promote proper adherence. Depending on the substrate materials and conditions, surface preparation methods may include hydroblasting or pressure washing. Any breaches found in the structure are typically repaired before coating to prevent system leakage or groundwater infiltration.

2.2 Research topics

The results of CPC demonstration project F11-AR24 (Wilson, Drozdz, and Mathis 2016) identified several significant areas of interest for follow-on study (as summarized below).

1. *Polyurea coatings for concrete and metal protection require investigation under high-velocity cavitating flow conditions* (see 3.2.8).
2. *Application of polyurea in a simple, single-layer nonproprietary configuration requires investigation.* The previous demonstration used a patented, semi-structural three-layer application. DoD requires nonproprietary application methods to gain the full value and potential of polyurea for infrastructure renewal (see 3.2.2).
3. *Field repair methods for damaged polyurea liners require investigation.* A finding of the F11-AR24 project was that the demonstrated polyurea coating technology lacks a field repair method that Directorates of Public Works (DPWs) can use for damaged locations. It is not cost effective for DPWs to hire specialized contractors to apply proprietary techniques for simple, small-area repairs (see 3.2.10).
4. *Polyurea protection of metal infrastructure requires investigation.* A finding of F11-AR24 was that the polyurea coating adheres well to the concrete and brick, but adhesion to metals was not tested. Metals in sewer infrastructure are frequently exposed to acidic and generally corrosive conditions (see 3.2.6).
5. *Polyurea liner performance in the presence of continuous leaks requires additional research.* A finding of F11-AR24 was that the polyurea coating/liner reduces groundwater infiltration and inflow (I&I) in sanitary sewer manholes. However, before the coating is applied, the contractor must use other measures to stop leaks in the manholes. If the leaks reoccur while the liner is in place, the polyurea barrier may fail by losing adhesion to the manhole wall. It is difficult to evaluate this failure mode in normal manholes, because the presence of groundwater around the manhole is usually intermittent (see 3.2.7).

The following additional topics of interest emerged and are also addressed:

- Polyurea and its various types of formulations (see 3.2.1).
- Polyurea and its varying application systems (see 3.2.2).
- Polyurea compared to other wastewater rehabilitation products (see 3.2.3).
- Perception of polyurea in industry (see 3.2.4).
- Processes involved in transporting, storing, and applying polyurea (see 3.2.5).
- Polyurea against abrasive conditions (see 3.2.8).
- Hazards involved with the use polyurea (see 3.2.9).
- Removal and disposal of polyuria (see 3.2.11).

2.3 Tools and methods

2.3.1 User survey

A user survey provided a better understanding of polyurea liner performance. The survey was conducted by the authors via telephone or email to 23 U.S. municipalities and two DoD DPWs. The survey's seven questions were about technology performance, vendors, and the extent to which polyurea is used for infrastructure rehabilitation, as listed below.

1. Where/how did you use a polyurea product? Was it used in sewers or elsewhere?
2. Would you use polyurea again in the future?
3. Do you know who the vendor and/or material supplier was?
4. What other products did you consider or have tried?
5. Are there any problems you encountered or information you think could be useful to us?
6. Have repairs to the polyurea coating ever been needed? How are repairs done?
7. Do you know of any other towns or cities using polyurea?

See section 3.2.4 for discussion of the findings from users who responded to the survey.

2.3.2 Literature review

A literature review supplemented the market survey. During a review of tests performed by other facilities on polyurea and a review of current literature, an additional seven questions were added for consideration during the current project, as listed below.

1. How is polyurea perceived in industry?
2. What are the application and removal processes for polyurea?
3. How is polyurea transported and stored?
4. What should be done with polyurea after it is removed?
5. What are the hazards involved with the use of polyurea?
6. What types of corrosion can polyurea withstand?
7. How does polyurea compare to other products used for rehabilitation of stormwater and wastewater structures?

3 Discussion

3.1 Applicable industry standards

The authors identified several industry standards that are applicable to the use of polyurea in wastewater systems. Because manufacturers make various formulations of the material which exhibit different properties, exact specifications and quantitative criteria will vary. Provided below are identified industry standards which are directly or indirectly applicable to polyurea and its application. Note that, in the current work, the authors did not find there to be industry-wide adoption of specific standards for the use of polyurea.

Table 1 shows industry standards that may relate to polyurea.

Table 1. Standards which may relate to polyurea.

Standard Number	Standard Date	Title
29 CFR 1910.134	2006	Respiratory Protection Standard
ASTM D 412 – 15a	2015	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D 624 - 00	2012	Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers
ASTM D 2240 - 15	2015	Standard Test Method for Rubber Property—Durometer Hardness
ASTM D 4060	2014	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D 7055 – 14	2015	Standard Practice for Preparation (by Abrasive Cleaning) of Hot-Rolled Carbon Steel Panels for Testing of Coatings
ASTM D 4258 – 05	2012	Standard Practice for Surface Cleaning Concrete for Coating
ASTM D 4259 – 88	2012	Standard Practice for Abrading Concrete
ASTM A849 – 15	2015	Standard Specification for Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drainage Pipe
ASTM F1216	2009	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube

Standard Number	Standard Date	Title
SSPC Coatings Specification No. 44	2013	Liquid Applied Organic Polymeric Coatings and Linings for Concrete Structures in Municipal Wastewater Facilities, Performance Based
SSPC Coating Application Standard No. 14	2012	Application of Thick Film Polyurea and Polyurethane Coatings to Concrete and Steel Using Plural Component Equipment

The International Concrete Repair Institute (ICRI) uses a Concrete Surface Profile (CSP) system, designated by numbers that range from 1 (smoothest) to 9 (roughest), to gauge the level of roughness of a given concrete surface. Table 2 shows the approximations that one company uses to achieve optimum results for coating thickness based on the ICRI CSP system.

Table 2. Example of coating thickness needed to achieve each ICRI CSP numbers (VersaFlex 2015, 2).

CSP Number	Coating Thickness Needed
CSP-1 & CSP-2	45–55 mils
CSP-3	55–60 mils
CSP-4	60–65 mils
CSP-5	65–70 mils
CSP-6	70–75 mils
CSP-7	75–80 mils
CSP-8	80–85 mils
CSP-9	85–90 mils

3.2 Findings

3.2.1 Polyurea formulations

Manufacturers offer different formulations of polyurea to address different project requirements. All forms of polyurea have an A-side (polyisocyanate prepolymer) and a B-side (resin blend formulation). The resin blend formulation is composed of varying sizes of amine-terminated molecules. The factors that determine the properties a given blend of polyurea are the choice of amine being used and the ratio of the selected amines included in the coating. The absence of intentionally added hydroxyls makes the system a *pure* polyurea. Polyurea *hybrids* possess hydroxyl-containing products (polyols) and may also contain catalysts for system reactivity and additives such as pigments (Stephenson et al. 2012, 3).

Both the resin blend and isocyanate components can be either aromatic or aliphatic in nature. Depending on the choice of resin or isocyanate, the polyurea blend can be classified as aromatic-based or aliphatic-based. Aromatic-based polyurea blends tend to lose color faster than aliphatic-based systems, when exposed to natural or artificial light. Aliphatic-based blends tend to retain their color, but they are more expensive due to the raw materials used in preparing the formulation. A good comparison between the two is the temperature at which softening and/or decomposition of the polymer begin to occur. For aromatic-based formulations, this temperature is about 230°C–260°C. For aliphatic-based formulations, this temperature is about 60°C–80°C (Primeaux II 2016).

Because manufacturers provide several formulations, the project designer can choose the appropriate product to suit the situation. Manufacturers should be able to assist project designers with identifying which blend will perform best. In general, polyurea formulations will provide wastewater infrastructure with a protective barrier against impact damage, abrasion, UV damage, sulfuric acid, and chemicals commonly found in wastewater streams.

3.2.2 Application systems

Just as there are different blends of polyurea, there are different application systems. An application system refers to a particular blend or a combination of blends of polyurea in addition to any other components included to provide different qualities suitable for a given environment. For instance, the liner system demonstrated in the CPC Project F11-AR24 is a three-layer application system with an initial layer of polyurea, then a layer of polyurethane foam, then a top layer of polyurea (Wilson, Drodz, and Mathis 2016). An epoxy-based primer is typically used before the application of the main three layers. The first and third layers are composed of polyurea and are typically less than 80 mils thick. The middle layer of polyurethane foam is usually greater than 500 mils in thickness. The patent on the three-layer system was first established as U.S. Patent 5,618,616 A (Hume and Danielle 1997). During an author’s phone conversation with a company official on 1 March 2016, he reported the patent had expired, and other companies had begun using similar processes.

The main purpose of a three-layer system such as the one described above is to provide more semi-structural support than a traditional one-layer system. In what is typically referred to as a stress-skin liner, the combination of different layers (including foam) develops a type of synergistic strength and flexibility that is greater than that of a single-layer coating (SpectraTech 2017). Though a system like this offers more structural support than other systems, it should not be used as a standalone solution to correct structural damage.

Other application systems exist besides the three-layer system. Sometimes polyurea used with a primer is referred to as a two-layer system, but it is also commonly categorized as a single-layer system because there is only one layer of polyurea. Such application systems are nonproprietary and commonly used. It is important to note that a true single-layer application of polyurea may not be the most effective option in a rehabilitation environment due to the rough substrate surface which increases the risk of coating failure, according to the conversation noted above by an author with a company official.

3.2.3 Comparisons with other no-dig methods and material options

Polyurea application is not the only rehabilitation method for stormwater and wastewater structures. For large-diameter structures, commonly used “no-dig” rehabilitation methods include: cured-in-place liners (CIP), formed in place, and slip lining. Additional options include polyurethane, epoxy, coal tar epoxy, chemical/cement grouts, reinforced gunite/shotcrete, and others (Selvakumar and Tafuri 2012). Of these, epoxy appears to be the main competitor against polyurea for wastewater rehabilitation protection.

One municipality stated during the survey that they believe whenever more geopolymer applicators exist and the product becomes more economical, geopolymer will become the main competitor against epoxy and polyurea. However, geopolymers offer differentiation by providing structural support.

3.2.3.1 Open cut method

Open cut, or total replacement, is a traditional option for wastewater rehabilitation, but it requires the whole structure to be removed and replaced instead of rehabilitated. Total replacement is expensive, and it causes disruption to the public at or near the site. Total replacement has become less popular over the past two decades, since alternatives have become more feasible.

3.2.3.2 Cured-in-place liners

CIP liners are commonly used by municipalities to correct corrosion damage. They are almost exclusively used for piping. CIP requires a "bag" system to be custom made before installation to a premeasured size, and the system is later impregnated with resin at the jobsite. This bag is then fed into the desired pipe or hole and is steam-pressure-injected for about 1–2 hr to cure. When using CIP, it is imperative that the structure it is being used on has been thoroughly cleaned and that all debris has been removed. Additionally, all recessed voids must be filled to eliminate issues in annular space. If not properly installed, the open cut method must be used to correct the problem. CIP provides structural rehabilitation, eliminates I&I, and protects against corrosion. CIP is labor intensive and demands specialized equipment. (ASCE 2009, 52).

3.2.3.3 Formed-in-place method

Formed-in-place (concrete) is another method that is almost exclusively used on piping. It involves creating a form within the structure that conforms to its shape. Spacing of 3 in. (or so) is left between the form and the structure's surface, to later be filled with concrete. Once the concrete cures and the form is removed, a new surface of concrete is left in the same shape as preexisting piping. The preexisting surface should be thoroughly cleaned, and all loose material should be removed before installation (AP/M Permaform 1999).

3.2.3.4 Slip lining

Slip linings are typically intended for use on pipes with no joint settlements or misalignments, and which have ample hydraulic capacity. This method is applied by inserting a new pipe of a smaller diameter into the existing pipe. The annular space is then grouted in order to create a seal. Slip lining is a simple and relatively inexpensive solution, but it is limited to pipes that have a uniform diameter throughout and no varying cross sections (Najafi 2013, 20).

3.2.3.5 Epoxy

Epoxy appears to be the main competitor against polyurea for wastewater rehabilitation protection. The two products provide many similar features but are intrinsically different. Both liners are commonly spray-applied and used for corrosion mitigation. However, epoxy compared to polyurea is a much stiffer coating with a longer pot life, a much longer cure time, and a higher tensile strength. It can be formulated for moisture and surface tolerance in order to achieve optimum adhesion (ASCE 2009, 52). Epoxy is used by many of the municipalities contacted during the market survey (refer to section 2.3.1 for survey questions and 3.2.4 for results). Polyurea is a relatively new technology, whereas epoxy has become established over time as a viable rehabilitation method.

Both products serve the purpose of corrosion prevention, but each has its advantages and disadvantages. A liner manufacturer that manufactures both epoxy and polyurea coatings was interviewed by authors on 24 November 2015, to distinguish each product's capabilities and limitations. This contact stated that all of their lining systems respond differently to various chemical environments. He said their epoxy lining system is the most common lining system they supply for wastewater environments, claiming that it provides the longest service life when exposed to chemical attack. He also mentioned, however, that epoxy resin's limited flexibility makes it susceptible to damage in environments where unstable soil is present. For environments subject to shift, expansion, or contraction, he recommended that an elastomeric polyurethane and/or polyurea system be used. In general, he claimed that polyurethane and/or polyurea systems do not offer as much chemical resistance as epoxies, but they do provide necessary flexibility that epoxy cannot deliver for some environments. In constant immersion environments, the manufacturer claimed that epoxies perform better than polyureas.

UV resistance is another important comparison to make between epoxy and polyurea. UV lighting treatment has begun to replace chlorination and chemical processes in wastewater systems for disinfection to destroy micro-organisms, pathogens, viruses, and molds. However, UV exposure has been found to be extremely destructive to epoxies, deteriorating them in a matter of months. Polyurea, however, has shown superior resistance to UV radiation (Primeaux II 2016).

In terms of cost, the previously mentioned coatings manufacturer claimed that both technologies have relatively the same application costs, but the epoxy coating itself is slightly more expensive. When examining the cost of the entire installation process, however, the cost of the material is not a major component of the total cost (Primeaux II 2016). Primeaux explained that a significant portion of the overall cost to install a liner includes surface preparation, application, and especially loss of functionality of the system during downtime (Primeaux II 2016).

When considering surface preparation, the previously mentioned coatings manufacturer claimed that polyurea liners typically require a much more aggressive surface preparation to achieve maximum mechanical bond to the host substrate. In his experience, polyurea systems have a higher number of delamination issues than epoxy systems. Underground concrete substrates will almost always have a higher moisture percentage than above-ground concrete and thus, they require a penetrating epoxy prime coat in order to “seal” the concrete prior to application. This prime coat is necessary because polyurea, by nature, is moisture sensitive and does not bond well to damp surfaces. Epoxy, on the other hand, handles moisture fairly well and can be applied to damp substrates. This manufacturer recommended that a penetrating prime coat still be used, however, prior to epoxy coating application.

Considering application time and downtime, polyurea can often be applied to the desired thickness in one application and dries to the touch in seconds. The surface coated by polyurea can usually be put back into service in 4 hr, depending on the polyurea formulation and liquid composition of the wastewater. Other high-build (thickness) coating systems like epoxies can require 24 hr between multiple coats and, in total, can require a week of time before the lined system can return to service (Primeaux II 2016).

3.2.3.6 Polyurethane

Polyurethane is a common liner material used in wastewater applications. It is chemically similar to polyurea. Like polyurea, it can be formulated to adopt different properties. Two main categories of polyurethane formulations are (a) rigid polyurethane and (b) elastomeric polyurethane.

Rigid polyurethane systems create a hard, dense protective barrier with good resistance to chemicals and corrosion. Elastomeric polyurethanes offer a stretchable, elastic quality and tend to have good impact strength and flexibility. However, elastomeric polyurethanes have been found to have poor tensile adhesion and cathodic disbondment (Timleck 2000). Polyurethane is often used in combination with other liner materials to offer extra support or resistance.

3.2.3.7 Coal tar epoxy

Coal tar epoxy has traditionally been used in concrete and steel wastewater tanks and structures as a protective coating. It is a relatively inexpensive material and offers protection against mild chemical attack and abrasion (Peters 2016). However, there are health hazards associated with it. Coal tar epoxy is a carcinogen, presenting a risk to those applying it and working around it. Also, one source claimed that the application surface must be completely dry, meaning that some surfaces must be out of service for at least 28 days before application (WaterWorld 2003).

3.2.3.8 Chemical/cement grouts

Chemical/cement grouts are good at providing permanent fixes in combination with other liners. Grouts are typically used to repair any damages before a liner is applied. Most cementitious materials are shotcrete applied. Though cementitious materials offer good structural support and elimination of I&I, many formulations corrode in chemical conditions found in wastewater systems. High alumina or calcium aluminate hybrid formulas are better suited for defense against microbiologically induced corrosion (MIC) (ASCE 2009, 51).

3.2.4 User perceptions and attitudes

In total, 25 municipalities (including 2 military sites) were contacted for the market survey—14 replied, and 9 of those reported use of polyurea in their wastewater systems. Within that group of 9 municipalities, 5 reported a willingness to use polyurea again in the future, 2 reported they would not use polyurea again, and 2 were unsure whether they would use the product again. Of the 5 that replied but had not used polyurea before, 2 municipalities stated that they would be open to a demonstration of the material. The main reason given by municipalities for deciding not to use polyurea again in the future, or for never trying it in the first place, was experience with, or fear of, adhesion failure.

Many municipalities did not use polyurea because they did not desire to switch from another system with which they are satisfied. Other concerns that some municipalities stated regarding polyurea included high cost and an unfamiliarity with the product. Another finding of the survey was that epoxy is widely used by many municipalities in their wastewater systems. This is likely due in part to epoxy being available for many more years than polyurea. Other products used by municipalities included cured-in-place pipe (CIPP) and polymer-modified cements.

3.2.5 Transporting, storing, and applying polyurea

Polyurea is typically transported using two 55 gal drums, one consisting of the isocyanate and the other of the polyol resin (the amine) (Polyurea.com 2016a). According to the manufacturer's specifications for shipping and storing the product, the drums are taken to the project site . After the drums are on site, material is moved into separate containers to be used by the spray gun. Typically, the equipment used to spray the polyurea has two metering pumps to proportion the mix, which is also warmed through heated hoses. As the materials leave the spray gun's nozzle, they are combined in a 1:1 ratio. The two materials should not be combined until the moment they leave the nozzle, due to polyurea's extremely fast cure time.

A crucial part of any application of polyurea is the surface preparation. After the surface is inspected, a cleaning of all surfaces is required with a "High Pressure Water Cleaning" (5,000 psi/min). This is followed by a dry or wet abrasive blast to achieve the required profile and porosity. Then, all surface defects are repaired with an approved, high early-strength repair mortar or through mechanical means like grinders, chipping hammers, etc. Lastly, all surfaces are cleaned off with a clean-air blast or water cleaning, and then left to dry prior to primer/coating application, preferably for at least 12 hr (Raven Lining Systems 2014).

Polyurea is reported by various manufacturers as suitable for application in a very wide range of temperatures. Claims between companies vary. One company reports, "It can be spray applied at temperatures ranging from 20°F to 150°F…[It] has excellent chemical resistance, excellent water insensitivity, and a temperature range of -40°F to 250°F" (SpectraShield

Liner Systems 2000, 15). Another source reports that "Polyurea reactivity is independent of the ambient temperature. Polyurea reacts fast – and it will react at the same speed regardless of the temperature. It can be 100°F or -25°F and the reactivity is almost the same" (polyurea.com 2016b). The acceptable temperature range for the product chosen should be verified with the manufacturer's instructions before beginning application.

Workers applying polyurea should have prior training, supervision, and experience. Due to fast cure time, thickness testing cannot be done without removing a section of the polyurea, checking the thickness of the removed portion, and then, applying a new coat of polyurea in the place where the section was removed. In order to reduce error and create a monolithic liner, remote centrifugal spray equipment is sometimes used to reduce inconsistencies caused handheld equipment (Trenchless Technology 2011).

3.2.6 Use of polyurea on steel

Polyurea is known to work well with steel. It is used to coat steel water tanks and other steel infrastructure. An industry report conducted in 2001 showed that 10% of all polyurea applications at that time were used on steel (Posey 2016).

When any substrate is to be lined or coated, it is important to consider the coefficient of linear thermal expansion (CLTE) of each material, especially in environments with fluctuating temperatures. It is important for the substrate and liner's CLTE values to be relatively close so that the two materials expand and contract with varying temperatures but at similar rates. This closeness of CLTE values decreases the likelihood of adhesion failure as temperatures shift. Typical blends of polyurea have a CLTE value of 2–6 µin/in-°F. This value is very close to that of steel's (6–7 µin/in-°F), especially when compared to that of other common liner materials like epoxy, which has a CLTE value of 20–25 µin/in-°F (Primeaux II 2016). Furthermore, the elastomeric properties of polyurea can overcome slight differences in CTLE.

To apply polyurea on steel, follow manufacturer's recommendations. Typically, manufacturers' requirements are strict. Manufacturers will require the steel to be completely free of rust, salt, dirt, and other contaminants, which is achieved by blasting the surface. The steel must be blasted until it reaches a "near white metal." ASTM D7055–14 should be referenced for standard practice of surface preparation for the steel. All surface imperfections should be fixed (e.g., welds have to be free of voids and spurs, and sharp protrusions should be ground smooth) to reduce the chance of adhesion failure of the polyurea. It is not vital for a primer to be used with polyurea for steel applications. As long as the surface has been blasted to a near-white finish, a primer is only necessary if flash rusting needs to be prevented.

3.2.7 Inflow and infiltration issues (I&I)

I&I is a common issue related to wastewater systems. The additional water that enters the sewers causes unnecessary costs because it must be treated. In some cases, I&I can cause water levels to exceed the sewer system's capacity, leading to overflow issues that impact water quality and public health (Metropolitan Council 2016). Technically, I&I are two different processes. Inflow refers to water entering the wastewater system through other water lines, and infiltration refers to groundwater seeping into the interior through cracks and holes in the infrastructure. However, the singular term I&I is commonly used to describe one or the other, and this usage is followed in this report. Polyurea is used to reduce infiltration.

Many manufacturers claim that polyurea lining systems can prevent I&I. Some municipalities from the market survey claimed to use polyurea lining systems specifically for the purpose of preventing I&I (section 3.2.4). Polyurea is able to perform this task, but only when it is used in conjunction with other products. Because of polyurea's fast cure rate and viscosity, it does not seep into and fill small holes and cracks. Instead, the material simply bridges over them, making it inefficient at plugging and stopping leaks entirely on its own. If I&I is not stopped before the application of polyurea, the moisture and pressure can cause blistering and adhesion failure that ruins the liner.

Though polyurea used alone may not treat I&I, polyurea works very well with other materials in order to prevent future I&I from occurring. Grouts are often used to stop existing I&I before the application of a liner (Trenchless Technology 2011). There are many types of grouts and methods to apply them, but their basic use in collaboration with a liner typically remains the same: the grout is applied to the affected areas to stop I&I and then, the liner is applied over the entire surface, including the newly formed grout seals. The new liner acts to stabilize the repairs and also offers some resistance to new leakage. When steps are taken to stop

I&I prior to the application of a polyurea liner, the possibility of future I&I should be sharply reduced.

3.2.8 Abrasion and cavitation protection

Abrasion is an erosive process commonly found in stormwater infrastructure and occasionally found in wastewater. Since abrasives-containing fluids pass through these systems, the liner material wears down over time. Polyurea was chosen as the concrete liner for an intermediate-level outlet on the Tehri Dam project in India (Sharma and Vishnoi 2007). Tests were run to determine whether the liner would maintain its integrity when exposed to the conditions of abrasive silt flowing through the structure at approximately 20 m per second. The results of polyurea's resistance to wet and dry abrasion vs. the results of concrete, epoxy, and steel are listed in Table 3.

Table 3. Tehri Dam project test results (data from Sharma and Vishnoi 2007).

Test	Concrete	Epoxy	Steel	Polyurea
Wet Abrasion	Weight loss 137 g per ASTM C1138	Weight loss 28 g per ASTM C1138	Weight loss 0.0825 g per cavitation erosion test	Weight loss 0.0747 g per cavitation erosion test and 8.0 g per ASTM C1138
Dry Abrasion	N/A	Weight loss 0.023 g per ASTM D4060	N/A	Weight loss 0.003 g per ASTM D4060

The test results were clear that polyurea was a good candidate for resisting the outlet's intensely abrasive conditions. Polyurea's flexibility makes it extremely resistant to abrasion. Where epoxy is rigid and can easily be cracked by force, polyurea is able to bend and flex to maintain its seal and hold up against large forces (Sharma and Vishnoi 2007, 741).

Cavitation is a less common occurrence in stormwater systems, and it is even less likely to occur in wastewater systems. In order for cavitation to occur, high velocities of flowing water are required. Storm drains are designed to use gravity flow which can sometimes yield cavitating velocities given the right conditions, but these conditions are uncommon. In the literature review, Choi and Chahine (2015) showed that testing was performed on different thicknesses of polyurea coatings to determine the material's performance against cavitating jets. The results showed that polyurea coatings failed at a fast rate when cavitating jet pressures were higher than 700 psi (a relatively low threshold). The failure was due to extreme deformation, local heating, and plastic flow of the material. Visual evidence of the damage showed a crater with the material pushed outward, which formed a ridge around the crater. It was believed that heat accumulation from large strain work caused the material to become soft and easily deformed by the mean stagnation pressure of the jet. Polyurea coatings performed better at smaller thicknesses and lower temperatures (Choi and Chahine 2015, 1 and 8).

3.2.9 Application hazards

As a finding of the survey (section 3.2.4), possible hazards of using products containing isocyanates were reported. An individual in the infrastructure rehabilitation industry reported instances of improper precautionary measures being used by applicators and health problems of individuals exposed to the polyurea. This topic was further investigated, and the highlights of the investigation are discussed below.

Isocyanate is a main component in polyurea, and therefore it is imperative that proper precautions are taken to protect workers from the hazards of exposure to isocyanate. When people are exposed to isocyanates, they become susceptible to developing respiratory sensitization, and in extreme cases death could occur (NIOSH 2006, 11). Respiratory sensitization can occur not only from inhalation of the isocyanate, but also from dermal exposure. Exposure of the skin to the isocyanate can also cause dermal sensitization, resulting in a rash, itching, hives, and swelling of the extremities. Isocyanates have low water solubility, making them very difficult to wash off skin and/or clothing (OSHA [Occupational Safety and Health Administration] 2013, 9).

Proper attire for anyone potentially exposed to isocyanates includes chemical-resistant gloves and clothing, safety goggles or face shield, and a respirator, in accordance with OSHA rules codified in 29 CFR 1910.134 (OSHA 2013, 20).

Considering environmental safety, there has been much debate and testing in order to ensure polyurea is safe to use. The California Department of Transportation was reported in 2012 to have effectively banned the use of spray-on liners containing isocyanates, including polyurea (DeCou 2012 in Donaldson and Whelton 2012, 2). It is not known as of this writing whether the ban has been lifted. To test hazards of MDI (methylene diphenyl diisocyanate) exposure, a 30-day leaching test in 2013, according to American Society of Civil Engineers (ASCE) standards, to see how stormwater infrastructure coatings affect water quality. This test showed that the isocyanates in polyurea caused a reduction of pH by 1.0–1.2 pH units during the first two testing periods. The alkalinity, chemical oxygen demand (COD), total organic carbon (TOC), and total nitrogen were calculated every 3 days for the exposure's duration. From these values, an estimate of aqueous contaminant level was calculated by using 12 in., 24 in., and 36 in. pipe diameters. The results predicted an increase in contaminant levels as the diameters decreased (Whelton et al. 2013, 747–750).

In order to prevent environmental contamination from use of polyurea liners, the Virginia Department of Transportation recommended the following specifications be considered (in Donaldson and Whelton 2012, 15–16):

1. The contractor should perform all installations in the dry.
2. The contractor should install a temporary curtain at the outlet and inlet to prevent overspray during installation.
3. The contractor should reinstate water flow no sooner than 24 hr after installation.
4. The contractor should thoroughly rinse the cured liner with clean water and then, capture and properly dispose of the rinse water prior to reinstating flow.
5. The contractor should employ the services of a qualified independent environmental services or environmental consultant to collect the following samples:
    a. pre-rehabilitation water and soil samples within 3 ft of the pipe ends (or otherwise as close as possible), upstream and downstream of the pipe location;
    b. water and soil samples within 3 ft of the pipe ends (or otherwise as close as possible), upstream and downstream of the pipe location, within one week after the liner has cured.

Although polyurea can be potentially harmful if proper precautions are not taken, it is still approved for use in potable water systems even though they are held to higher standards than those of wastewater and stormwater systems. For potable water, there is a standard maximum coating thickness and minimum vessel diameter that must be maintained based on testing done with specific formulations of polyurea (Primeaux II 2016). Polyurea sprays comply with the material specifications of ASTM A849 and also ASTM F1216 to determine coating thickness for some project-specific liners (in Donaldson and Whelton 2012, 9). Polyurea installers should always be aware of these standards and ensure that the coating is applied properly to assure the safety of the workers and environment.

3.2.10 Repairs

Polyurea applicators and manufacturers reported that if failure of a polyurea coating occurs, the damaged section of polyurea is blasted off. Repairs are to be made to the structure if it was the source of the failure. Then new primer, polyurea, and polyurethane foam (if part of the system) is applied to the cleared section to match the original application.

3.2.11 Removal and disposal

Manufacturers stated that pressure washing or sandblasting is used to remove polyurea from the surface. At this time, polyurea recycling is not common practice. Therefore, if the product needs to be removed, it must be disposed of according to instructions from the manufacturer.

4 Economic Analysis

4.1 Costs and assumptions

This project only included polyurea market, industry, and technical research. This project did not include a demonstration, although a successful physical demonstration was previously performed under a separate project with a return on investment (ROI) range of 1 to 5.5, but no criteria for implementation were suggested as a result of that project (Wilson, Drozdz, and Mathis 2016).

Since the current project did not include a demonstration, a generic ROI is calculated by assuming the additional research and criteria draft standards lead to polyurea installation in a fraction of DoD-owned manholes under certain situations. The ROI is based on a set of assumptions and RSMeans industry data described in the points below.

a. The baseline cost assumes replacement of a significantly deteriorated manhole with a new manhole. There are several associated costs including the material cost of the manhole with a frame and cover which is estimated to be $1,650 based on 2011 RSMeans data, adjusted for inflation. It is assumed the cost of excavation, footing, and backfill will cost the same amount as the material. Gaskets will cost $300. Moreover, in locations with high H2S or other corrosive conditions, additional measures are needed, such as a manhole liner, so assume the use of a manhole liner at a cost of $25/square foot. The liner cost is the area of the inside of the manhole (4' x 3.14 x 6') x $25/sf = $1,900 per manhole. The calculated conventional manhole cost with a liner is $1650 + $1650 + $300 + $1900 = $5500. Sources for cost figures are from RSMeans and Concrete Conservation Incorporated.

Table 4 shows baseline total costs of a manhole replacement (with and without a liner). The alternative case’s cost summary is shown in Table 5.

Table 4. Estimated cost per manhole replacement-baseline case (sources: RSMeans and Concrete Conservation Incorporated).

Item	Cost ($)	Comment	Total Cost ($)
Conventional concrete manhole with frame and cover	1,650	RSMeans data, 2011	
Adjustment for inflation in manhole cost	100	Total inflation factor of 6% (2012–2014)	
Excavation, footing, backfill	1,650	Installation cost assumed equal to material cost.	
Gaskets	300	RSMeans	
Total cost per manhole (no liner)			3,700
Cost of polyurea liner (if applicable), with expected life of 30 yr.	1,900	With highly corrosive conditions; 75+ sq ft @ $25 per sq ft	
Total cost per manhole (with liner)			5,500

Table 5. Cost summary for alternative case-rehabilitation using polyurea liner.

Baseline Case Costs	Cost ($)
Cost of polyurea liner per square foot	25
Cost of polyurea liner per 4' interior diameter and 6' deep concrete manhole	1,900

b. Some significantly deteriorated sanitary manholes will be suitable for rehabilitation with polyurea liners. The Army Installation Status Report (ISR) program for Data Year 2012 reports over 1,550 miles of sewer pipe in Facility Category Group F83200 Sewage/Waste Collection Lines), counting only those that have a rating of Red (failing) or Black (failed) condition (U.S. Army 2012). This figure includes combined sewers, but not storm sewers. Sanitary manholes are required every 400–800 ft, depending on the terrain and size of pipe. This analysis has assumed an average of 500 linear feet of pipe between manholes, although the actual average spacing is probably shorter. Therefore, the number of Army sanitary manholes in failing condition is roughly 1,550 miles x 5,280 ft per mile / 500 ft ≈ 16,400 manholes. This number of manholes does not include Navy or Air Force facilities.

c. Considering manholes only - if the Army replaces only 5% per year of the 16,400 (already failing) manholes, that number equals 820 manholes per year (0.05 x 16,400). In some instances, polyurea liners will be justified on a case-by-case basis. The calculation here assumes that only 100 of the 820 manholes to be replaced per year would receive polyurea liners. Only those manholes in the worst condition, per ISR, are considered here (U.S. Army 2012). These include many of those in the most corrosive or otherwise harsh environments, and so they are good candidates for polyurea liners.

d. Per the above calculations, the annual baseline cost of conventional new manholes with liners is $5,500 x 100 or $550,000. New manhole life cycle is assumed to be 50 years. This annual baseline cost is shown in Table 6 and placed in column B of the ROI table (Table 7).

   The comparative new system cost of polyurea liners is $190,000 ($1,900 x 100). The ROI calculation accounts for a 5-year phase-in of the new technology. Service life for the new technology is 30 years. This new system cost is placed in column D of the ROI table (Table 7) and shown here in Table 6.

Table 6. Annual cost summary for 100 replacements vs. 100 rehabilitations with polyurea.

Case	Cost ($)	Expected Service Life (Years)
Replacement of manholes	$550,000	50
Rehabilitations with polyurea	$190,000	30

e. There is added benefit from preventing sanitary sewer pipe infiltration and inflow at wastewater treatment plants by avoiding operation and maintenance costs. Such a cost-saving benefit is not accounted for in this calculation, but it would improve the ROI.

4.2 Return on investment

The ROI for this technology was computed using methods prescribed by Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. Based on the costs and assumptions given in section 4.2, the expected ROI for a representative application of nonproprietary, liquid-applied polyurea sewer liners would be 35.24.

Table 7. Return on investment (ROI) calculation.

Return on Investment Calculation

Investment Required		100,000
Return on Investment Ratio	35.24	Percent 3524%
Net Present Value of Costs and Benefits/Savings	3,300,698	6,824,785	3,524,087

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	550,000		550,000		514,030	514,030	
2	550,000		480,000		419,232	480,370	61,138
3	550,000		411,000		335,499	448,965	113,466
4	550,000		340,000		259,386	419,595	160,209
5	550,000		272,000		193,936	392,150	198,214
6	550,000		190,000		126,597	366,465	239,868
7	550,000		190,000		118,313	342,485	224,172
8	550,000		190,000		110,580	320,100	209,520
9	550,000		190,000		103,341	299,145	195,804
10	550,000		190,000		96,577	279,565	182,988
11	550,000		190,000		90,269	261,305	171,036
12	550,000		190,000		84,360	244,200	159,840
13	550,000		190,000		78,850	228,250	149,400
14	550,000		190,000		73,682	213,290	139,608
15	550,000		190,000		68,856	199,320	130,464
16	550,000		190,000		64,353	186,285	121,932
17	550,000		190,000		60,154	174,130	113,976
18	550,000		190,000		56,221	162,745	106,524
19	550,000		190,000		52,535	152,075	99,540
20	550,000		190,000		49,096	142,120	93,024
21	550,000		190,000		45,885	132,825	86,940
22	550,000		190,000		42,883	124,135	81,252
23	550,000		190,000		40,071	115,995	75,924
24	550,000		190,000		37,449	108,405	70,956
25	550,000		190,000		34,998	101,310	66,312
26	550,000		190,000		32,718	94,710	61,992
27	550,000		190,000		30,571	88,495	57,924
28	550,000		190,000		28,576	82,720	54,144
29	550,000		190,000		26,714	77,330	50,616
30	550,000		190,000		24,966	72,270	47,304

5 Conclusions and Recommendations

5.1 Conclusions

5.1.1 Polyurea formulations

The ability to create varying formulations of polyurea makes it a versatile material. Different formulations can give the liner the properties necessary to achieve the best results for a given environment. It is important to use the proper formulation of polyurea for the job it is intended to perform. If the material needs to protect against certain types of corrosion, check with the manufacturer to ensure the product can withstand the elements of that environment.

5.1.2 Polyurea application systems

The existence of more than one type of polyurea application system enables versatility in material choice. Before choosing what liner configuration to use for a project, the designer should consider the advantages and disadvantages of each system. The three-layer system, for example, offers additional rigidity and resistance to penetration by hydrogen sulfide (H_2S) gas. A system such as this, however, cannot be used alone to correct structural damage, and it requires more costly materials and effort. Primers require more initial cost, but they also aid in prevention of adhesion failure, the most commonly found source of polyurea failure.

5.1.3 Polyurea and other product comparisons

Different wastewater rehabilitation products are suited to different scenarios. Polyurea has been available for some time and is accepted in the industry. Geopolymers offer good resistance to corrosion but are a relatively new technology. Open cut total replacement is common, but it is extremely costly and requires heavy construction. This method is suitable for systems beyond repair and requiring replacement. For rehabilitation, using a product like polyurea will cause significantly less disruption to the daily lives of the community, and the cost will be much less.

Polyurethane is a common wastewater liner material that offers many different properties across different formulations. Rigid polyurethane offers good resistance to chemical corrosion, and elastomeric polyurethane offers good flexibility and impact resistance. Polyurethane is often used in conjunction with other liner materials to offer additional support or resistance.

Coal tar epoxies are inexpensive, but they do not offer the level of protection other liners do. Health or safety issues may arise as a result of the product being a carcinogen. Additionally, some cases require substrates to be left to dry for an excessive amount of time, leading to money lost from downtime. Polyurea is thought to offer better protection, and it does not require excessive downtime.

Cured-in-place and formed-in-place pipe are used for smaller and larger piping respectively. They can be very effective, but require custom manufacturing before application and are very labor intensive to apply. Slip linings are designed for pipes with uniform diameters throughout and no varying cross sections, giving them serious limitations. Sprayed-in-place lining like polyurea is able to accommodate different geometries and does not require as much preparation, since no custom manufacturing is required beforehand.

Chemical/cement grouts perform well at repairing damage, but they do not offer much corrosion resistance. They are appropriate for making preparations for other liners. If cementitious material is being spray applied, the material itself should be a high alumina or calcium aluminate formula in order to better prevent against chemical corrosion. Otherwise, it will have no effect against the microbially induced corrosion (MIC) found in wastewater systems. Cementitious applications can offer good structural support.

5.1.4 Polyurea versus epoxy

Epoxy and polyurea liners are each suited to certain environments. Epoxies provide exceptional moisture and surface tolerance. However, they are not as flexible as polyurea, nor do they cure as quickly. Epoxies are suitable for high-moisture areas and in areas that do not experience much thermal expansion and contraction. Epoxies provide better protection against chemically corrosive environments, and they work better under constant immersion. Both polyurea and epoxy can successfully mitigate corrosion in wastewater systems. For systems that might experience movement, expansion, or contraction, polyurea is recommended due to its flexibility. Also polyurea may be better for abrasive conditions with high suspended solids and high-flow velocity. Polyurea, in addition, offers resistance to UV lighting that epoxy cannot provide.

Both products have similar costs for the material and installation, but the epoxy liner may be slightly more expensive than polyurea. Polyurea liners tend to require more thorough surface preparation to minimize adhesion failure. However, polyureas cure much faster than epoxies, and polyureas typically offer a much shorter return to service time, saving down time cost.

Therefore, in moist, stable, chemically harsh, or immersive conditions, epoxy liners tend to provide a better solution to corrosion protection. In unstable, abrasive, and UV conditions, polyureas offer a more suitable lining.

5.1.5 Industry perception of polyurea

Several municipalities surveyed were satisfied with the product. Those that were unsatisfied had experienced adhesion failures, which are commonly the result of improper surface preparation. Many municipalities used epoxy as their primary wastewater liner, but use of polyurea is gaining interest.

5.1.6 Transporting, storing, and applying polyurea

Polyurea's components cannot be combined until application due to rapid curing time. Application requires specialized equipment to combine the two components as they leave the nozzle. Before application, proper surface preparation is essential to reduce chances of adhesion failure.

Many coatings can only be applied in a very limited range of temperatures. This makes polyurea unique, since it can be applied in a wide range of temperatures. This range of temperatures gives polyurea a distinctive advantage over its competition.

Since polyurea cures rapidly, checking its thickness during application is difficult. It is important for the application crew to have proper training to ensure that the thickness meets specifications. In some situations, centrifugal spray equipment can reduce human error.

5.1.7 Using polyurea on steel

Polyurea manufacturers and applicators confirmed that polyurea can be applied to steel. Polyurea will expand and contract with the steel substrate as temperature changes. It is important, however, that all rust and other imperfections be removed before application. As long as the steel is blasted to a near-white finish and all imperfections are removed, primers are only necessary under conditions where flash rusting may occur.

5.1.8 Polyurea and inflow and infiltration (I&I)

Polyurea is able to prevent future development of I&I. However by itself, polyurea is not able to effectively stop existing I&I. All previous I&I should be stopped before the liner is applied. Chemical grouts are often used for this purpose. Once the polyurea liner is in place and all previous I&I has been stopped, the possibility of future I&I is greatly reduced.

5.1.9 Polyurea against abrasion and cavitation

Polyurea is an extremely durable material that is able to bend and flex under applied pressure without cracking. Polyurea linings performed well on the Tehri Dam Project under extremely abrasive conditions. Polyurea should be considered for protecting infrastructure from abrasive conditions when needed.

Polyurea is not recommended to address cavitation in stormwater and wastewater systems.

5.1.10 Application and use hazards for polyurea

Working directly with or around dangerous levels of isocyanates can lead to respiratory sensitization and other harmful effects. Thus, it is imperative that proper steps be taken in order to protect the workers from exposure. Proper protection is referenced in section 3.2.9.

The California Department of Transportation had banned the use of spray-on liners containing isocyanates including polyurea due to concerns regarding environmental and worker safety. However, other information suggests the substance may be used safely if installed properly, as several departments of transportation have approved its use.

5.1.11 Repairs of polyurea liners

Polyurea liners are physically tough, so the need for repair should be minimized with proper application. There is a method for repairing damage to a polyurea coating, but no “quick-fix” solutions were found. Military installation staff will probably need contracted assistance from professional applicators to make repairs.

5.1.12 Removal and disposal of polyurea

Methods for removing and disposing of polyurea do exist, and these methods do not tend to be expensive or difficult. Polyurea can be removed by abrasive blasting. At this time, polyurea recycling is not common practice., so the material must be disposed of according to manufacturer’s instructions and in accordance with all applicable government regulations.

5.2 Recommendations

5.2.1 Applicability

Polyurea is a viable option for DoD wastewater and stormwater infrastructure because they provide protection against acid and other corrosive conditions found in wastewater and stormwater systems. However, polyurea is applicable only in limited situations. In addition, the cost effectiveness of polyurea should be considered on a case-by-case bases; other products may offer better solutions for a given environment. Polyurea liners should be considered in particular for environments with high movement, high-velocity abrasive flows, or exposure to ultraviolet radiation. Because of rapid cure times, polyurea also may be advantageous for projects that require a short downtime for operation of the infrastructure.

5.2.2 Preparation and protection

Proper surface preparation is important. Proper measures must be taken to repair any existing damage—including stopping I&I—before application. Field inspection is essential, because the surface must be thoroughly cleaned and prepped.

Workers should always be properly protected from isocyanates. In situations where the presence of isocyanate in the environment is particularly sensitive, designers should consider the factors discussed in this report.

5.2.3 Implementation

DoD engineering criteria documents should be revised to guide the implementation of polyurea liners. A Criteria Change Request will be submitted by the authors to the document's technical proponent, to recommend the guide specification changes described below.

The following specification document has been identified for revision upon completion of this project: UFGS 09 96 00, *High-Performance Coatings*. A proposed new section of this UFGS is provided in the appendix of this report. Also, the added wording to UFGS 09 96 00 should be referenced in the existing criteria document: UFC 3-240-01, *Wastewater Collection*. A proposed addition to the UFC is provided in the appendix of this report.

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Appendix: Recommendations for Implementing Polyurea Technology Into DoD Specifications and Criteria

The authors' recommendations for additions or changes to certain areas of DoD construction guides are given below (shown by blue-colored text).

Proposed updates to UFGS 09 96 00, High-Performance Coatings

Section 1.2, Submittals

Incorporate polyurea as a Submittal Description (SD) in the SD categories, as indicated below:

SD-03 Product Data

Heat-Resistant Coatings[; G[, [_____]]]
Epoxy Coatings[; G[, [_____]]]
Polyurethane Coatings[; G[, [_____]]]
Chlorinated-Rubber Coatings[; G[, [_____]]]
Polyurea [; G[, [_____]]]

SD-07 Certificates

Heat-Resistant Coatings[; G[, [_____]]]
Epoxy Coatings[; G[, [_____]]]
Polyurethane Coatings[; G[, [_____]]]
Chlorinated-Rubber Coatings[; G[, [_____]]]
Polyurea [; G[, [_____]]]

Section 2.2, Materials

(Add a subsection for polyurea materials. Recommended draft text is provided below, by subsection):

Section 2.2.4, Polyurea Coatings

Note: Section 2.2.4 is only valid for wastewater and stormwater infrastructure.

Note: Polyurea-based coatings will be advantageous where surfaces to be coated require high abrasion resistance, chemical resistance, corrosion resistance, or UV resistance. Polyurea coatings offer a short downtime for the application period and flexibility if the structure is subject to movement. Polyurea can be applied in a wide range of temperatures and humidity levels.

Note: Polyurea-based coatings are a two-part elastomer made up of isocyanates and amines. Due to the isocyanates in polyurea, it is a hazardous material and proper safety precautions must be followed. Work is only to be performed by certified professionals.

Note: Consider dry-film thickness value as a minimum and may be revised as required to suit conditions and surface use.

Ensure all polyurea coatings use ASTM SI10. The minimum for the polyurea coating's dry film thickness is 45 mils. Indicate the finish color on the schedule.

Section 2.2.4.1, Concrete Surface Coating

Apply a minimum of one primary coat on concrete surfaces. Provide prime coats as recommended by the manufacturer. Ensure the prime coat fills the surface pores with a total dry-film thickness of not less than 0.07 millimeter (3 mils). The primer is followed by a finish coat of polyurea. A coat of polyurethane foam may be applied between the primer and a finish coat of polyurea, or between two layers of polyurea. All polyurea based coatings are as specified.

Section 2.2.4.2, Masonry Surfaces Coatings

Block fillers may be used if recommended by the coating manufacturer for the substrate and end use of the coated surface. Fill surface pores with block filler at a total film thickness of not less than 0.25 millimeter (10 mils). Apply a minimum of one prime coat on masonry surfaces. Provide prime coats as recommended by the manufacturer. Ensure the prime coat has a total dry-film thickness of not less than 0.07 millimeter (3 mils). A coat of polyurethane foam may be applied between the primer and a finish coat of polyurea, or between two layers of polyurea. All polyurea based coatings are as specified.

2.2.4.3, Ferrous and Galvanized Metal Surface Coatings

Surface should be blasted to a near white finish, as specified in section 3.1.3.3 Steel Substrates. A prime coat may be used to prevent flash rusting, as recommended by the manufacturer for the substrate to be coated. Ensure the prime coat fills the surface pores with a total dry-film thickness of not less than 0.05 millimeter (2 mils). A coat of polyurethane foam may be applied between the primer and a finish coat of polyurea, or between two layers of polyurea. All polyurea based coatings are as specified by the manufacturer.

Proposed updates to UFC 3-240-01, Wastewater Collection

Section 3-7, Evaluation and Rehabilitation of Existing Sewer Systems

(Include polyurea as recommended below.)

Evaluate and rehabilitate existing sanitary sewer systems in accordance with the latest edition of WEF Manual of Practice FD-6, *Existing Sewer Evaluation and Rehabilitation*. See also UFGS 09 96 00, *High-Performance Coatings*, section 2.2.4, for information about polyurea liners.

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14. ABSTRACT

Corrosion of reinforced concrete in wastewater systems due to microbially generated sulfuric acid is a major problem for Department of Defense (DoD) facilities. A previous DoD-sponsored demonstration and validation project showed that liquid-applied polyurea liner technology can effectively rehabilitate wastewater systems and prevent further corrosion, but more work was needed before recommending the technology's adoption DoD-wide. This follow-on study explores and discusses additional issues and makes recommendations about polyurea's use. Issues explored include behavior under high-velocity flow conditions, additional application configurations, field repair methods, behavior on steel substrates, comparisons with other rehabilitation products, industry perception and use, and sewer inflow and infiltration. The approach included a survey of municipal practices plus a literature review. Results showed that polyurea liners can be useful in mitigating the effects of corrosion, especially when sewer and wastewater environments are subject to movement, abrasion, or ultraviolet radiation. Recommendations to the DoD's Corrosion Prevention and Control Program include adding a polyurea section to UFGS 09 96 00 High Performance Coatings and referencing UFGS 09 96 00 within UFC 3-240-01 Wastewater Collection. The return on investment for this effort is 35.24

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